CLAIMS

1. A method of measuring a system delay time between when a stimulus signal is applied to an input of an electro-acoustic system having at least one acoustic transducer and when a resulting audio signal produced by the at least one acoustic transducer in response to the stimulus signal is detected at a point of measurement, the method comprising:

generating a first signal having a repeatable sequence;

coupling the first signal to the electronic input of the electro-acoustic system as the stimulus signal, the acoustic transducer generating a resulting audio signal in response;

generating a second signal at an initial delay time subsequent to generating the first signal, the second signal having the repeatable sequence of the first signal;

converting the resulting audio signal detected at the point of measurement to a corresponding electronic signal;

comparing the corresponding electronic signal and the second signal for a plurality of delay times beginning with the initial delay time;

generating and recording for the plurality of delay times a corresponding plurality of signed correlation values having magnitudes indicative of the correlation between the corresponding electronic signal and the second signal at the respective delay time;

evaluating the plurality of correlation values for a peak correlation value corresponding to the peak correlation between the corresponding electronic signal and the second signal; and

selecting the delay time associated with the peak correlation value as the system delay time.

2. The method of claim 1 wherein the first and second signals comprise pseudo-random pink noise signals.

3. The method of claim 1 wherein generating the first and second signals comprise generating the first and second signals using separate signal sources.

4. The method of claim 1 wherein the first signal comprises live or recorded music.

5. The method of claim 1, further comprising calculating the distance from the acoustic center of the acoustic transducer to the point of measurement from the system delay time.

6. The method of claim 1, further comprising:

selecting a measurement frequency at which to measure the time between applying the stimulus signal and detecting the resulting audio signal; and

attenuating frequency components of the corresponding electronic signal and the second signal that are substantially greater than and less than the measurement frequency.

7. The method of claim 6 wherein selecting a measurement frequency comprises determining an energy center frequency for the acoustic transducer at which the total energy produced by the acoustic transducer for frequencies greater than the energy center frequency is substantially equal to the total energy produced by the acoustic transducer for frequencies less than the energy center frequency over a 20 hertz to 20,000 hertz frequency spectrum.

8. The method of claim 6 wherein the plurality of delay times for which a correlation value is generated comprises 96 delay times at increments of (1/24 x T), T being defined as the period of a wavelength at the measurement frequency.

9. The method of claim 6 wherein evaluating the plurality of recorded correlation values for a peak correlation value comprises:

determining a first peak correlation value having a first magnitude greater than a threshold value and further having a first polarity;

determining a second peak correlation value having a second magnitude greater than the threshold value, and further having a second polarity opposite of the first polarity;

selecting the greater of the first and second magnitudes as the peak correlation value when the measurement frequency is greater than or equal to 800 hertz and the ratio of the first and second magnitudes is greater than or equal to 1.8;

selecting the greater of the first and second magnitudes as the peak correlation value when the measurement frequency is less than 800 hertz and the ratio of the first and second magnitudes is greater than or equal to 3.0; and

selecting from the first and second peak correlation values the one having the lower associated delay time as the peak correlation value when the measurement frequency is greater than or equal to 800 hertz and the ratio of the first and second magnitudes is less than 1.8, and when the measurement frequency less than 800 hertz and the ratio of the first and second magnitudes is less than 3.0.

10. The method of claim 1, further comprising determining a polarity of the acoustic transducer with respect to the first signal from the sign of the correlation signal.

11. The method of claim 1, further comprising determining an approximate time-of-flight for an impulse signal applied to the input of the electro-acoustic system to be reproduced by the acoustic transducer and detected at the point of measurement, the approximate time used to determine the initial delay time.

12. The method of claim 11 wherein determining an approximate time-of-flight comprises measuring the time for a sine ping applied to the input of the electro-acoustic system and reproduced by the acoustic transducer to be detected at the point of measurement.

13. The method of claim 11 wherein the initial delay time is greater than the approximate time-of-flight and the plurality of delay times for which the correlation values are generated is incrementally decreased from the initial delay time.

14. The method of claim 13, further comprising selecting a measurement frequency at which to measure the time between applying the stimulus signal and detecting the resulting audio signal, and wherein the initial delay time is greater than the approximate time-of-flight by (1.5 x T), T being defined as the period of a wavelength at the measurement frequency.

15. The method of claim 6, further comprising:

setting the delay time of the second signal to a first delay time that is less than the system delay time;

generating a signed correlation value for the first delay time;

incrementing the delay time of the second signal and generating a new signed correlation value until there are two occurrences of the magnitude of the new signed correlation value being less than the previous signed correlation value; and

selecting the delay time associated with the previous signed correlation value as the system delay time.

16. The method of claim 15 wherein setting the delay time comprises setting the first delay time to be equal to the system delay time less (1/6 x T), T being defined as the period of a wavelength at the measurement frequency.

17. The method of claim 15 wherein incrementing the delay time comprises incrementing the delay time in increments of (1/36 x T), T being defined as the period of a wavelength at the measurement frequency.

18. The method of claim 15 wherein generating a new signed correlation value comprises:

sampling the value of an output signal of a mixer receiving the corresponding electronic signal and the second signal 256 times at 40 millisecond intervals;

converting each sampled value to a corresponding digital value; and

averaging the corresponding digital values.

19. The method of claim 1 wherein delay times of the plurality are automatically generated.

20. The method of claim 1 wherein generating a correlation value for each of the plurality of delay times comprises:

sampling the value of an output signal of a mixer receiving the corresponding electronic signal and the second signal a predetermined number of times at an interval;

converting each sampled value to a corresponding digital value; and

averaging the corresponding digital values.

21. The method of claim 20 wherein the predetermined number of times is 128 and the interval is 20 milliseconds.

22. A method of measuring a time-of-flight for an audio signal generated by a selected one of a plurality of acoustic transducers of an electro-acoustic system to reach a point of measurement, comprising:

generating a first pseudo-random noise signal having a repeatable sequence as the stimulus signal applied to the electro-acoustic system;

generating a second pseudo-random noise signal at a source delay time subsequent to generating the first noise signal, the second noise signal having the repeatable sequence of the first noise signal;

converting an audio signal generated by the selected acoustic transducer in response to the stimulus signal into an electronic signal when the audio signal is detected at the point of measurement;

comparing the electronic signal and the second noise signal for a plurality of delay times beginning with the source delay time;

generating and recording for the plurality of delay times a corresponding plurality of signed average values having magnitudes indicative of the correlation between the electronic signal and the second noise signal;

evaluating the plurality of signed average values for a peak correlation value corresponding to the maximum correlation between the electronic signal and the second noise signal; and

selecting the delay time associated with the peak correlation value as the time-of-flight.

23. The method of claim 22 wherein generating the first and second signals comprise generating the first and second signals using separate signal sources.

24. The method of claim 22 wherein delay times of the plurality are automatically generated.

25. The method of claim 22, further comprising calculating the distance from an acoustic center of the acoustic transducer to the point of measurement from the time-of-flight.

26. The method of claim 22, further comprising:

selecting a measurement frequency at which to measure the time-of-flight; and

attenuating frequency components of the corresponding electronic signal and the second noise signal that are substantially greater than and less than the measurement frequency.

27. The method of claim 26 wherein selecting a measurement frequency comprises determining an energy center frequency for the acoustic transducer at which the total energy produced by the acoustic transducer for frequencies greater than the energy center frequency is substantially equal to the total energy produced by the acoustic transducer for frequencies less than the energy center frequency over a 20 hertz to 20,000 hertz frequency spectrum.

28. The method of claim 26 wherein the plurality of delay times for which the signed average values are generated comprises 96 delay times at increments of (1/24 x T), T being defined as the period of a wavelength at the measurement frequency.

29. The method of claim 26 wherein evaluating the plurality of signed average values for the peak correlation value comprises:

determining a first peak correlation value having a first magnitude greater than a threshold value and further having a first polarity;

determining a second peak correlation value having a second magnitude greater than the threshold value, and further having a second polarity opposite of the first polarity;

selecting the greater of the first and second magnitudes as the peak correlation value when the measurement frequency is greater than or equal to 800 hertz and the ratio of the first and second magnitudes is greater than or equal to 1.8;

selecting the greater of the first and second magnitudes as the peak correlation value when the measurement frequency is less than 800 hertz and the ratio of the first and second magnitudes is greater than or equal to 3.0; and

selecting from the first and second peak correlation values the one having the lower associated delay time as the peak correlation value when the measurement frequency is greater than or equal to 800 hertz and the ratio of the first and second magnitudes is less than 1.8, and when the measurement frequency less than 800 hertz and the ratio of the first and second magnitudes is less than 3.0.

30. The method of claim 26, further comprising:

setting the delay time of the second noise signal to a first delay time that is less than the time-of-flight;

generating a signed average value for the first delay time;

incrementing the delay time of the second noise signal and generating a new signed average value until there are two occurrences of the magnitude of the new signed average value being less than the previous signed average value; and

selecting the delay time associated with the previous signed average value as the time-of-flight.

31. The method of claim 30 wherein setting the delay time comprises setting the first delay time to be equal to the time-of-flight less (1/6 x T), T being defined as the period of a wavelength at the measurement frequency.

32. The method of claim 30 wherein incrementing the delay time comprises incrementing the delay time in increments of (1/36 x T), T being defined as the period of a wavelength at the measurement frequency.

33. The method of claim 30 wherein generating a new signed average value comprises:

sampling the signed value of an output signal of a mixer receiving the corresponding electronic signal and the second noise signal 256 times at 40 millisecond intervals; and

averaging the corresponding digital values.

34. The method of claim 22, further comprising determining a polarity of the acoustic transducer with respect to the first noise signal from the sign of the peak correlation value.

35. The method of claim 22, further comprising determining an approximate time-of-flight for an impulse signal applied to the electro-acoustic system to be reproduced by the acoustic transducer and detected at the point of measurement, the approximate time-of-flight used to determine the source delay time.

36. The method of claim 35 wherein determining an approximate time-of-flight comprises measuring the time for a sine ping applied to the electro-acoustic system and reproduced by the acoustic transducer to be detected at the point of measurement.

37. The method of claim 35 wherein the source delay time is greater than the approximate time-of-flight and the plurality of delay times for which the signed average values are generated is incrementally decreased from the source delay time.

38. The method of claim 37, further comprising selecting a measurement frequency at which to measure the time-of-flight, and the initial delay time is greater than the approximate time-of-flight by (1.5 x T), T being defined as the period of a wavelength at the measurement frequency.

39. The method of claim 37 wherein generating a signed average value for each of the plurality of delay times comprises:

sampling the signed value of an output signal of a mixer receiving the corresponding electronic signal and the second signal a predetermined number of times at an interval;

converting each sampled signed value to a corresponding digital value; and

averaging the corresponding digital values.

40. The method of claim 39 wherein the predetermined number of times is 128 and the interval is 20 milliseconds.

41. A system for measuring a time delay between when a stimulus signal is applied to an input of an electro-acoustic system having at least one acoustic transducer and when a resulting audio signal produced by the at least one acoustic transducer in response to the stimulus signal is detected at a point of measurement, the system comprising:

a signal generator to generate first and second signals at first and second signal outputs of the signal generator, respectively, the first signal having a sequence and being applied through the first signal output to the electronic input of the electro-acoustic system as the stimulus signal, the second signal having the sequence of the first signal and being delayed with respect to the first signal by an adjustable delay time determined by the value of a delay control signal;

a microphone acoustically coupled to the at least one acoustic transducer of the electro-acoustic system and generating at a microphone output a resulting output signal corresponding to the resulting acoustic signal;

a mixer circuit coupled to the microphone output and the second signal output to receive the resulting output signal and second pseudo-random noise signal, respectively, the mixer circuit providing at a mixer output a mixer output signal having a magnitude indicative of a predetermined relationship between the resulting output signal and the second signal;

an analog-to-digital converter having an input coupled to the mixer output, the analog-to-digital converter generating at a converter output digital words corresponding to the magnitude of the mixer output signal applied to its input;

a memory for recording the digital words

a display for displaying information resulting from the measurement; and

a microprocessor coupled to the delay circuit for generating the delay control signal, the analog-to-digital converter for receiving the digital words corresponding to the magnitude of the mixer output signal, the memory for recording the digital words, and the display for providing information related the measurement to be displayed, the microprocessor measuring the time delay by:

initiating the signal generator to generate the first signal;

adjusting the delay control signal provided to the delay circuit to delay the second signal with respect to the first signal for a plurality of delay times;

recording for each of the plurality of delay times a digital word generated by the analog-to-digital converter;

evaluating the digital words for a selected digital word corresponding to the peak of the predetermined relationship between the resulting output signal and second signal; and

causing the display to provide visual information related to the selected digital word.

42. The system of claim 41 wherein the signal generator comprises a first pseudo-random noise generator to generate a first pseudo-random noise signal, and a second pseudo-random noise generator to generate a second pseudo-random noise signal.

43. The system of claim 42 wherein the frequency spectrum of the first and second pseudo-random noise signals have equal energy in each octave.

44. The system of claim 41 wherein the signal generator is adapted to generate a first signal comprising live or recorded music.

45. The system of claim 41 wherein the predetermined relationship between resulting output signal and the second signal comprises a correlation between resulting output signal and the second signal.

46. The system of claim 41, further comprising:

an oscillator coupled to the microprocessor and generating at an oscillator output a frequency control signal having a primary frequency component determined by the value of an oscillator frequency control signal provided by the microprocessor; and

first and second band-pass filters each attenuating frequency components of a signal applied to an input that are significantly greater than and less than a band-pass frequency corresponding to the value of the frequency control signal applied to a frequency control input by the oscillator, the first band-pass filter electrically coupled between the microphone output and the mixer circuit, and the second band-pass filter electrically coupled between the delay circuit output and the mixer circuit.

47. The system of claim 46 wherein the microprocessor determines the value of the oscillator frequency control signal by selecting an energy center frequency for the at least one acoustic transducer at which the total energy produced by the at least one acoustic transducer for frequencies greater than the energy center frequency is substantially equal to

the total energy produced by the at least one acoustic transducer for frequencies less than the energy center frequency.

48. The system of claim 41, further comprising a low-pass filter electrically coupled between the mixer output and the input of the analog-to-digital converter to limit the intensity of high frequency components of the mixer output signal.

49. The system of claim 41 wherein the mixer circuit comprises a four quadrant multiplier.

50. The system of claim 41 wherein the microprocessor is programmed to adjust the delay control signal automatically.

51. An analysis system for measuring a system delay time between when a stimulus signal is applied to an input of an electro-acoustic system having at least one acoustic transducer and when a resulting audio signal produced by the at least one acoustic transducer in response to the stimulus signal is detected at a point of measurement, the method comprising:

first signal generator means for generating a first signal having a repeatable sequence coupled to the electronic input to provide the first signal as the stimulus signal;

second signal generator means for generating a second signal at an initial delay time subsequent to generating the first signal, the second signal having the repeatable sequence of the first signal;

microphone means for converting the resulting audio signal detected at the point of measurement to a corresponding electronic signal, the microphone means acoustically coupled to the acoustic transducer;

comparison circuit means for comparing the corresponding electronic signal and the second signal for a plurality of delay times beginning with the initial delay time;

converter circuit means for generating for the plurality of delay times a corresponding plurality of signed correlation values having magnitudes indicative of the

correlation between the corresponding electronic signal and the second signal at the respective delay time;

memory means for storing the plurality of signed correlation values and the corresponding plurality of delay times;

microprocessor means for evaluating the plurality of correlation values for a peak correlation value corresponding to the peak correlation between the corresponding electronic signal and the second signal, the microprocessor means further selecting the delay time associated with the peak correlation value as the system delay time; and

display means coupled to the microprocessor means for displaying information generated by the microprocessor means.

52. The analysis system of claim 51 wherein the first and second signal generator means comprise pseudo-random pink noise generator means.

53. The analysis system of claim 51 wherein the first signal generator is adapted to generate a first signal comprising live or recorded music.

54. The analysis system of claim 51 wherein the microprocessor means further configured to calculate the distance from the acoustic center of the acoustic transducer to the point of measurement from the system delay time.

55. The analysis system of claim 51, further comprising:

a measurement frequency selection means coupled to the microprocessor means for providing a frequency control signal having a primary frequency component equal to a measurement frequency determined by the microprocessor means; and

a first and second filter means for attenuating frequency components of the corresponding electronic signal and the second signal, respectively, that are substantially greater than and less than the measurement frequency.

56. The analysis system of claim 55 wherein the microprocessor means selects as the measurement frequency an energy center frequency at which the total energy produced by the acoustic transducer for frequencies greater than the energy center frequency is substantially equal to the total energy produced by the acoustic transducer for frequencies less than the energy center frequency over a 20 hertz to 20,000 hertz frequency spectrum.

57. The analysis system of claim 51 wherein the comparison circuit means comprises a four quadrant multiplier.

58. The analysis system of claim 51 wherein the microprocessor means is programmed to select the delay time automatically.

59. The analysis system of claim 51, further comprising a low-pass filter means coupled between the comparison circuit means and converter circuit means for limiting the intensity of high frequency components of the correlation signal.

60. A system for measuring a time delay between when a stimulus signal is applied to an input of an electro-acoustic system having at least one acoustic transducer and when a resulting audio signal produced by the at least one acoustic transducer in response to the stimulus signal is detected at a point of measurement, the system comprising:

a first pseudo-random noise generator generating at a first noise output a first pseudo-random noise signal having a repeatable sequence, the first pseudo-random noise signal applied through the first noise output to the electronic input of the electro-acoustic system as the stimulus signal;

a microphone acoustically coupled to the at least one acoustic transducer of the electro-acoustic system and generating at a microphone output a resulting output signal corresponding to the resulting acoustic signal;

a second pseudo-random noise generator generating at a second noise output a second pseudo-random noise signal having the repeatable sequence of the first pseudo random noise signal, the second pseudo-random noise signal being delayed with respect to

the first pseudo-random noise signal by a delay time determined by the value of a delay control signal;

a comparison circuit coupled to the microphone output and the second noise output to compare the resulting output signal and the second pseudo-random noise signal, the comparison circuit providing at a comparison circuit output digital words corresponding to the magnitude of correlation between the resulting output signal and the second pseudo-random noise signal;

a memory circuit for storing the digital words provided by the comparison circuit;

a display for displaying information resulting from the measurement; and

a microprocessor coupled to the first and second pseudo-random noise generators for initiating the first pseudo-random noise signal and initiating the second pseudo-random at the delay time, the comparison circuit output for receiving the digital words, the memory circuit for providing the digital words for storage, and the display for providing data related to the measurement to be displayed, the microprocessor measuring the time delay by:

initiating the first pseudo-random noise generator to generate the first pseudo-random noise signal, and initiating the second pseudo-random noise generator at an initial delay time thereafter to generate the second pseudo-random noise signal;

providing the delay control signal to the second pseudo-random noise generator to adjust the delay value for a plurality of delay times;

storing for each of the plurality of delay times a digital word provided by the comparison circuit;

evaluating the digital words for a selected digital word corresponding to the peak correlation of the resulting output signal and second pseudo-random noise signal; and

causing the display to provide visual information related to the selected digital word.

ML

61. The system of claim 60, further comprising:

an oscillator coupled to the microprocessor and generating at an oscillator output a frequency control signal having a primary frequency component determined by the value of an oscillator frequency control signal provided by the microprocessor; and

first and second band-pass filters each attenuating frequency components of a signal applied to an input that are significantly greater than and less than a band-pass frequency corresponding to the value of the frequency control signal applied to a frequency control input by the oscillator, the first band-pass filter electrically coupled between the microphone output and the comparison circuit to attenuate the resulting output signal, and the second band-pass filter electrically coupled between the second noise output and the comparison circuit to attenuate the second pseudo-random noise signal.

62. The system of claim 61 wherein the microprocessor determines the value of the oscillator frequency control signal by selecting an energy center frequency for the at least one acoustic transducer at which the total energy produced by the at least one acoustic transducer for frequencies greater than the energy center frequency is substantially equal to the total energy produced by the at least one acoustic transducer for frequencies less than the energy center frequency.

63. The system of claim 60 wherein the comparison circuit comprises:

a mixer circuit coupled to the microphone output and the second noise output to provide at a mixer output a correlation signal having a magnitude corresponding to the correlation between the resulting output signal and the second pseudo-random noise signal; and

an analog-to-digital converter having an input coupled to the mixer output to sample the magnitude of the correlation signal and a converter output for providing the digital words.

64. The system of claim 63 wherein the comparison circuit further comprises a low-pass filter electrically coupled between the mixer output and the input of the

37

analog-to-digital converter to limit the intensity of high frequency components of the correlation signal.

65. The system of claim 63 wherein the mixer circuit comprises a four quadrant multiplier.

66. The system of claim 60 wherein the microprocessor is programmed to provide the delay control signal automatically.

67. The system of claim 60 wherein the frequency spectrum of the first and second pseudo-random noise signals have equal energy in each octave.